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(54) **MULTIPLE STEP PROGRAMMING IN A MEMORY DEVICE**

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G11C 16/04 (2006.01)

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(2013.01); **G11C 11/5642** (2013.01); **G11C**
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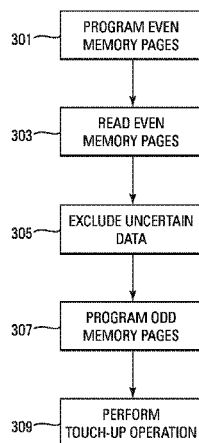
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PLLC

(57)

ABSTRACT

Method of operating a memory include programming a
memory cell and reading the memory cell to determine a
programmed threshold voltage of the memory cell. If the
programmed threshold voltage is within a threshold voltage
distribution of a plurality of threshold voltage distributions,
the memory cell is reprogrammed, and if the programmed
threshold voltage is not within a threshold voltage distribu-
tion of the plurality of threshold voltage distributions, the
memory cell is allowed to remain at the programmed thresh-
old voltage.

20 Claims, 5 Drawing Sheets



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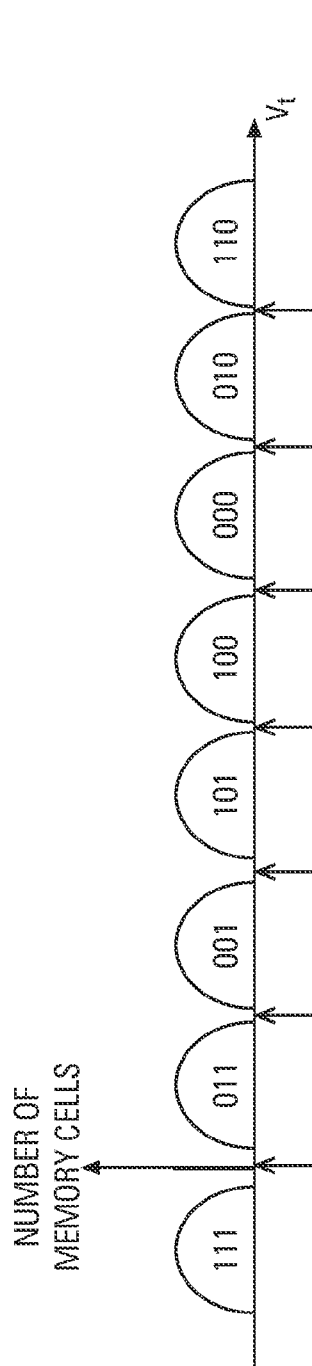


FIG. 1A
Prior Art

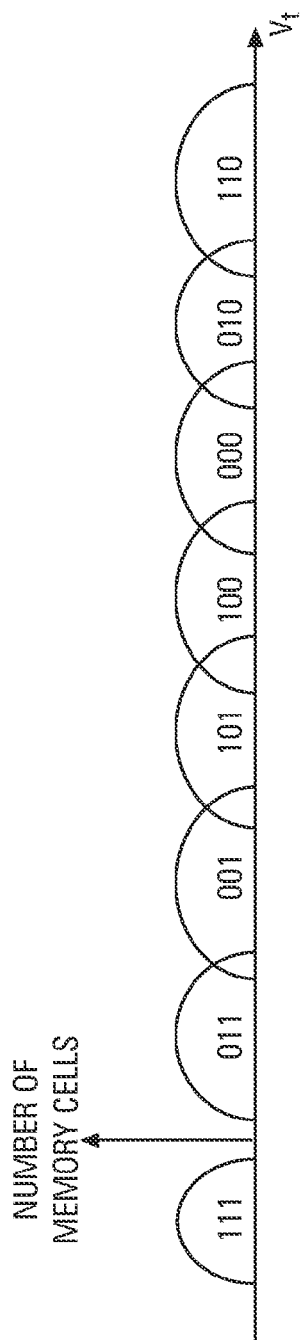


FIG. 1B
Prior Art

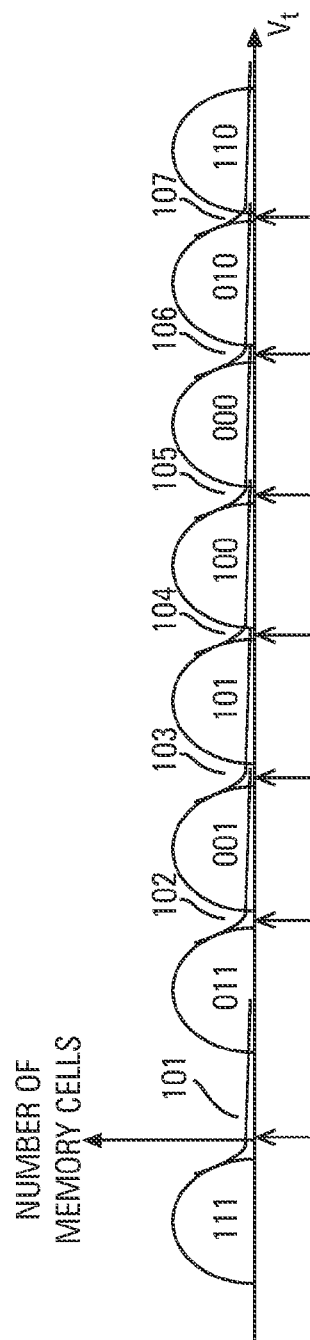


FIG. 1C
Prior Art

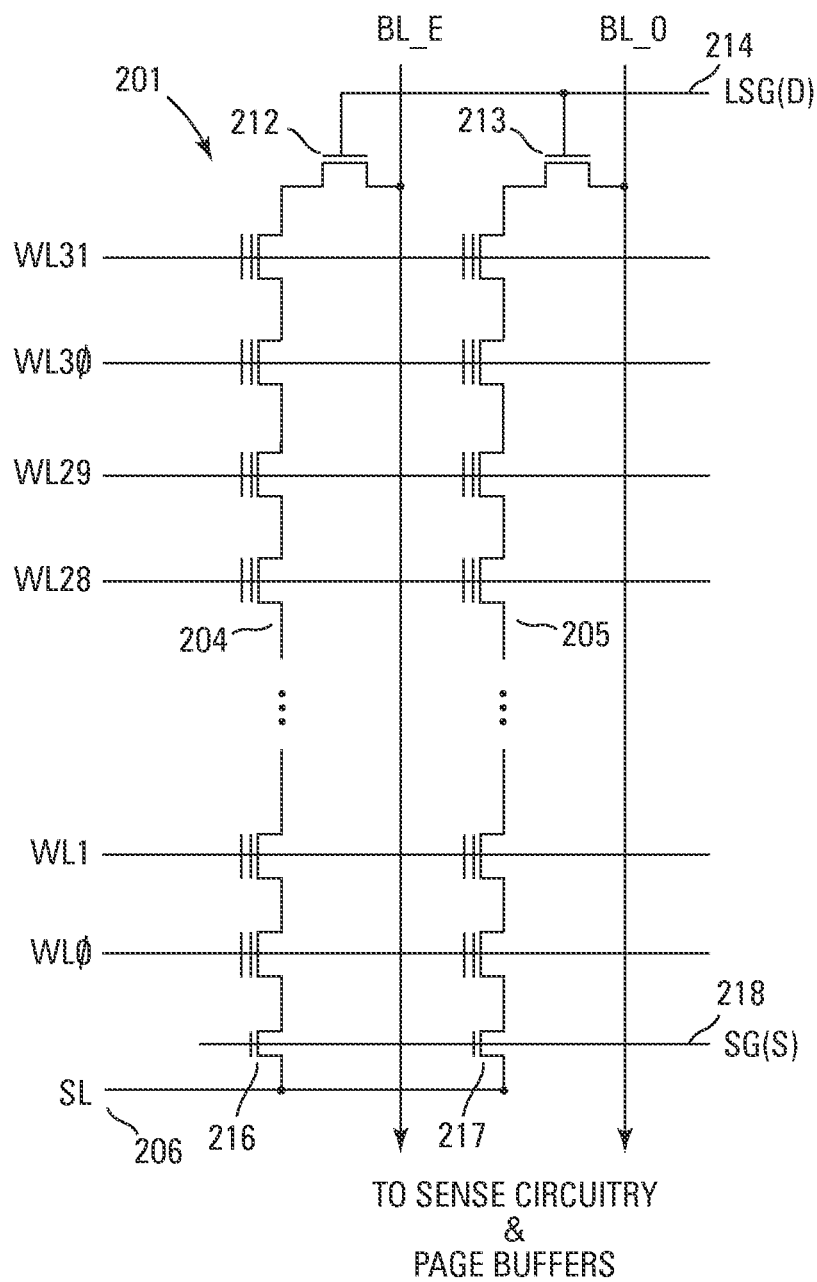
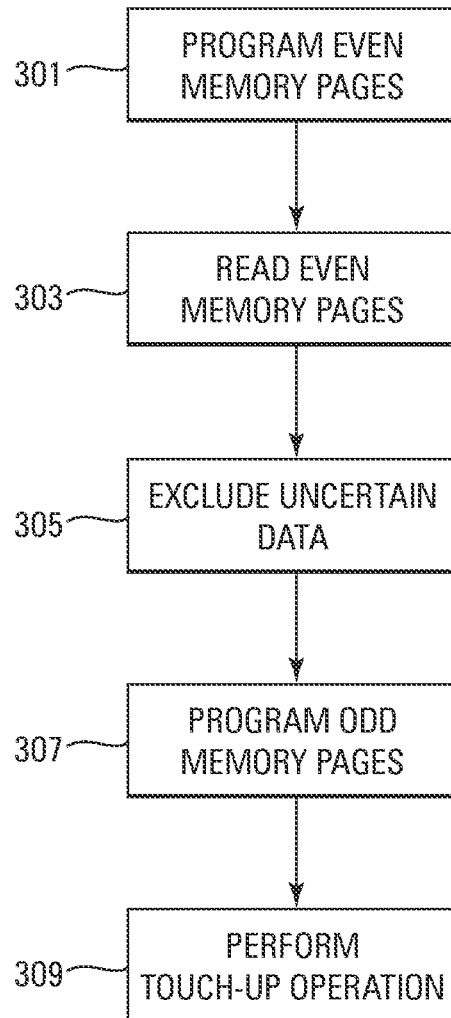
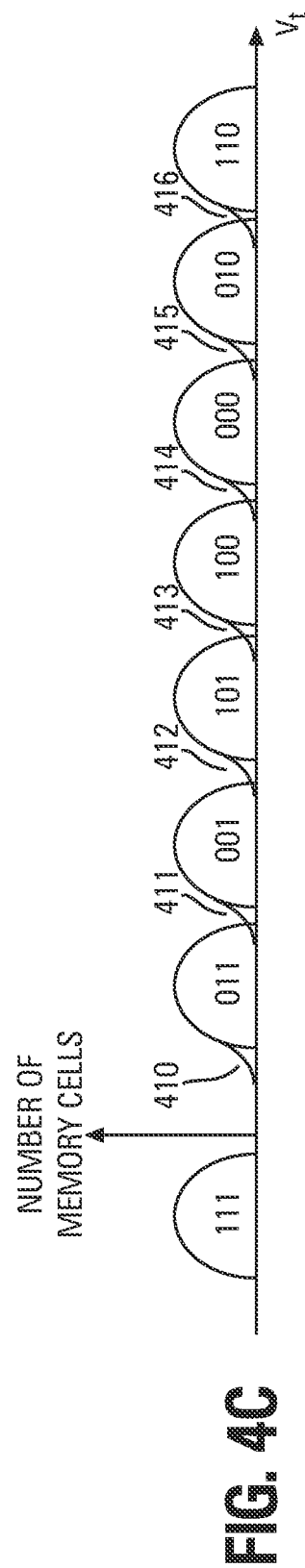
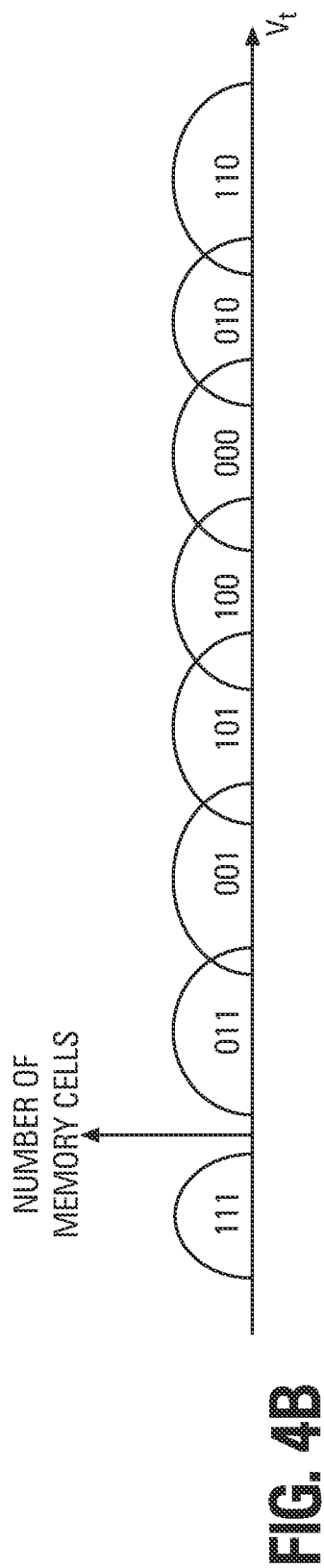
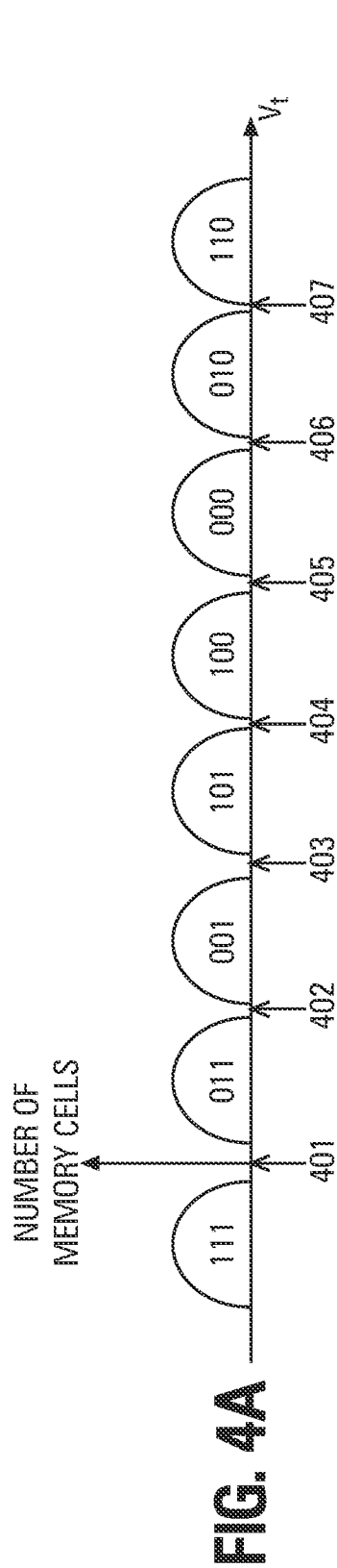
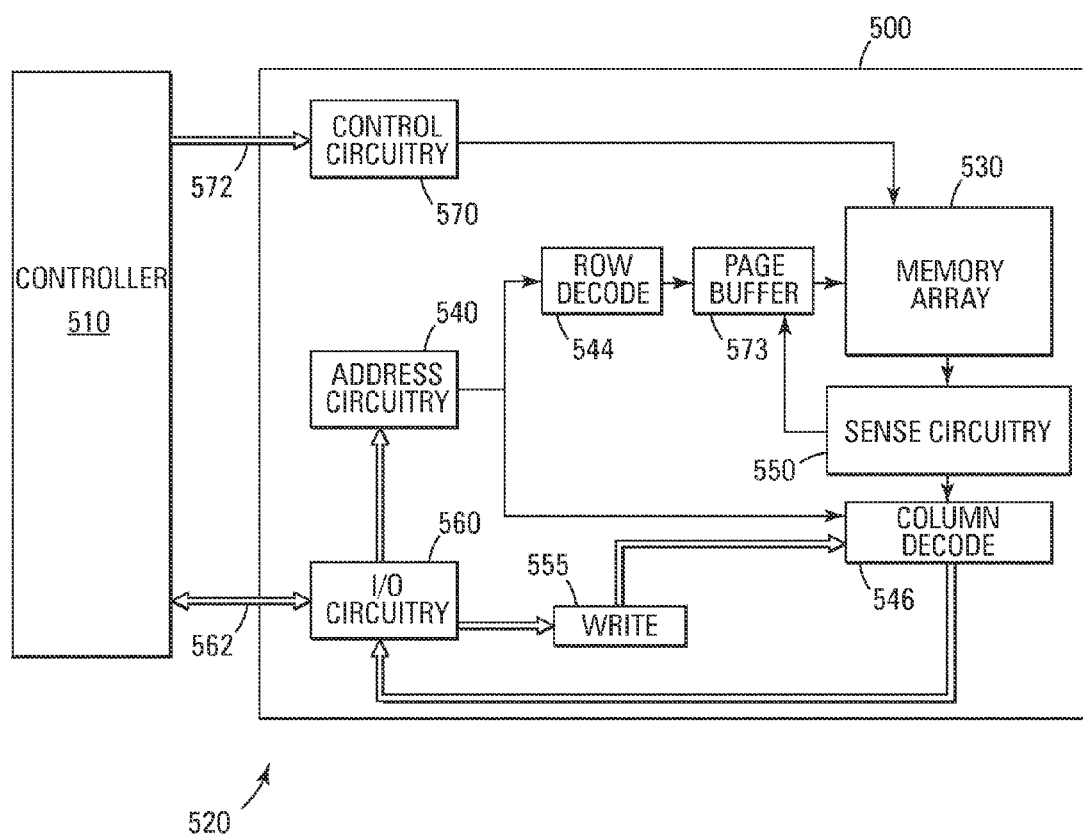


FIG. 2

**FIG. 3**



**FIG. 5**

MULTIPLE STEP PROGRAMMING IN A MEMORY DEVICE

RELATED APPLICATION

This Application is a Continuation of U.S. application Ser. No. 13/548,342, titled "MULTIPLE STEP PROGRAMMING IN A MEMORY DEVICE," filed Jul. 13, 2012, (Allowed) which is commonly assigned and incorporated herein by reference.

TECHNICAL FIELD

The present embodiments relate generally to memory and a particular embodiment relates to multiple step programming in a memory device.

BACKGROUND

Memory is typically provided as an integrated circuit(s) formed in and/or on semiconductor die(s), whether alone or in combination with another integrated circuit(s), and is commonly found in computers or other electronic devices. There are many different types of memory including random-access memory (RAM), read only memory (ROM), dynamic random access memory (DRAM), synchronous dynamic random access memory (SDRAM), and flash memory.

Flash memories have developed into a popular source of non-volatile memory for a wide range of electronic applications. Flash memories typically use a one-transistor memory cell that allows for high memory densities, high reliability, and low power consumption. Changes in threshold voltage of the cells, through programming of a charge storage structure, such as floating gates or trapping layers or other physical phenomena, determine the data state of each cell. Common uses for flash memory include personal computers, digital cameras, digital media players, digital recorders, games, appliances, vehicles, wireless devices, cellular telephones, and removable memory modules.

Single level memory cells (SLC) can store a single bit of data. Multi-level memory cells (MLC) can store two or more bits of data.

One problem that can occur with programming MLC memory is floating gate-to-floating gate capacitive coupling. The coupling can result in one memory cell disturbing adjacent memory cells, thus causing erroneous data to be stored in the adjacent memory cells.

Multiple step programming algorithms have been used to reduce the floating gate-to-floating gate coupling while also improving threshold voltage distribution widths. One particular multiple step programming operation comprises a prior art touch-up programming operation. This type of programming comprises programming an even page of memory first, reading the even page of memory, programming an odd page of memory then "touching-up" the even page of memory with additional programming pulses. FIGS. 1A-1C illustrate plots of threshold voltage distributions that can result from using a typical prior art multiple step programming operation.

FIG. 1A illustrates threshold voltage distributions after an even page of memory has been programmed. This figure shows an erased state (111) as well as seven programmed states (000-011).

The states of FIG. 1A are each represented by three bits that are the programmed "hard" data of a multiple bit programmed word. The hard data are the actual data, of the multiple bit programmed word, that are used. The programmed word can also comprise "soft" data that are used to

indicate a more precise location of the programmed state. For example, the area between each distribution that is indicated by the arrows is the soft data portion of the programmed word that indicates a location of its associated state to the right of the arrow. The soft data might be four bits of the multi-bit programmed word. Thus, the soft data can be considered the least significant bits (LSB) of the programmed word while the hard data can be considered the most significant bits (MSB) of the programmed word.

An even page read operation is performed after the even page has been programmed. Since programming of the memory pages might not be sequential, data stored in a page buffer for programming might be overwritten, after programming, by subsequent data to be programmed to the memory. Thus, during the even page read operation, the even page is read back out into the page buffer so that it can be further programmed during a subsequent touch-up programming operation, as discussed subsequently. This even page read can introduce errors into the programming operation, as subsequently described.

After the even page read is performed, the odd page of the memory cells is programmed. FIG. 1B illustrates the threshold voltage distributions after the odd page of memory has been programmed. The distributions have widened out due to the disturb effects of both program disturb (e.g., multiple programming voltages on the same word line) as well as floating gate-to-floating gate coupling.

It can be seen in FIG. 1B that the overlapping states have the potential to cause errors during reading of the memory since it could be unclear whether the read data belonged in, for example, the 001 state or the adjacent 101 state. In order to tighten up the distributions, an even page touch-up programming operation is performed.

The typical prior art even page touch-up programming operation comprises performing an additional program operation comprising additional programming pulses in order to program in the even page data read during the previous even page read operation. The even page touch-up programming operation programs the memory cells at the lower ends of the distributions to a high threshold voltage such that the memory cells at the lower ends of the distributions are moved up, thus tightening the distributions. FIG. 1C illustrates the distributions after the touch-up programming operation.

A problem with the above-described typical prior art multiple step programming operation is that, since the even page read operation does not use error correction coding, read errors are passed through uncorrected. This uncorrected data is then used during the touch-up programming operation. If the uncorrected data contains errors, the data is re-programmed with the errors during the touch-up operation. This can result in misplacement errors as shown in FIG. 1C by the "tails" 101-107 that are part of each distribution. These tails overlap with an adjacent distribution and represent the hard errors (e.g., error bits that are assigned a low probability of error by an error correction code (ECC) engine) transformed from the original soft errors (e.g., error bits that are assigned a high probability of error by the ECC engine) that can occur when assigning data to the wrong distribution during a read subsequent to the touch-up operation.

For the reasons stated above and for other reasons that will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art to reduce these programming errors caused by misplacement of data.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1C show plots of threshold voltage distributions resulting from typical prior art multiple step programming.

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FIG. 2 shows a schematic diagram of one embodiment of a portion of a memory array.

FIG. 3 shows a flow chart of one embodiment of a method for programming memory using a modified touch-up operation.

FIGS. 4A-4C show plots of threshold voltage distributions in accordance with the method for programming of FIG. 3.

FIG. 5 shows a block diagram of one embodiment of a system that can incorporate the multiple step programming method using the modified touch-up operation.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that form a part hereof and in which is shown, by way of illustration, specific embodiments. In the drawings, like numerals describe substantially similar components throughout the several views. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the present disclosure. The following detailed description is, therefore, not to be taken in a limiting sense.

FIG. 2 illustrates a schematic diagram of one embodiment of a portion of a NAND architecture memory array **201** comprising series strings of non-volatile memory cells. The present embodiments of the memory array are not limited to the illustrated NAND architecture. Alternate embodiments can use NOR, AND, PCM, or other architectures.

The memory array **201** comprises an array of non-volatile memory cells (e.g., floating gate) arranged in columns such as series strings **204**, **205**. Each of the cells is coupled drain to source in each series string **204**, **205**. An access line (e.g., word line) **WL0-WL31** that spans across multiple series strings **204**, **205** is coupled to the control gates of each memory cell in a row in order to bias the control gates of the memory cells in the row. Data lines, such as even/odd bit lines **BL_E**, **BL_O**, are coupled to the series strings and eventually coupled to sense circuitry that detects the state of each cell by sensing current or voltage on a selected bit line.

Each series string **204**, **205** of memory cells is coupled to a source line **206** by a source select gate **216**, **217** (e.g., transistor) and to an individual bit line **BL_E**, **BL_O** by a drain select gate **212**, **213** (e.g., transistor). The source select gates **216**, **217** are controlled by a source select gate control line **SG(S)** **218** coupled to their control gates. The drain select gates **212**, **213** are controlled by a drain select gate control line **SG(D)** **214**.

In a typical prior art programming of the memory array, each memory cell is individually programmed as either a single level cell (SLC) or a multiple level cell (MLC). The prior art uses a cell's threshold voltage (V_t) as an indication of the data stored in the cell. For example, in an SLC, a V_t of 2.5V might indicate a programmed cell (e.g., logical "0" state) while a V_t of -0.5V might indicate an erased cell (e.g., logical "1" state). An MLC uses multiple V_t ranges that each indicates a different state. Multiple level cells can take advantage of the analog nature of a traditional flash cell by assigning a specific bit pattern (e.g., 000-110) to a specific V_t range.

FIG. 3 illustrates a flow chart of one embodiment of a method for programming memory using a modified touch-up operation. The even page of a group of memory cells is programmed **301** from data in a page buffer. For example, the group of memory cells might comprise a block memory of memory cells.

The programming can be accomplished by a series of programming pulses applied to a word line coupled to control gates of the memory cells being programmed. A program

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verify operation after each programming pulse determines whether the memory cell has been programmed to its desired threshold voltage as dictated by the respective data to be programmed. When the memory cell turns on in response to a read voltage on the respective word line and produces a current or voltage on a respective bit line, as detected by the sense circuitry, the memory cell has been programmed.

FIG. 4A illustrates the threshold voltage distributions that can result from the even page programming. The x-axis of the plot is the threshold voltage V_t , and the y-axis is the number of memory cells at each threshold voltage. The distributions are the result of the fact that memory cells program at different rates. Thus, one programming pulse might move a first memory cell to the middle of the "011" state while another memory cell might only move to the left side of the "011" state after the same programming pulse.

While a large number of the memory cells end up being programmed to within the distributions, some of the memory cells end up in uncertain areas **401-407**. When this uncertain data is read, ECC correction is not used when it is later re-programmed. For example, if uncertain data is read from the uncertain area **403** between the threshold voltage distributions for states "001" and "101", they can be either one of the states, thus possibly resulting in the previously described misplacement errors if the data is read and later programmed as the wrong state.

Since the memory pages are not always programmed sequentially, the programmed even page or pages are read back out **303** to the page buffer. As subsequently described, this data is used later during a touch-up operation. During the reading of the page of data subsequent to the touch-up operation, an ECC engine checks the data for errors and attempts to perform corrections on the errors.

In order to reduce the hard errors caused by the touch-up operation passing through the read data "as-is" without ECC correction, the uncertain data is excluded, inhibited, or removed from the page buffer **305**. Thus, the uncertain data is left in the uncertain areas **401-407** between the distributions and are not further programmed during the subsequent touch-up operation.

The odd memory page or pages are then programmed **307**. This can be accomplished in a substantially similar manner to the even page or pages programming in that the data are programmed to their respective memory cells from the page buffer by increasing the threshold voltages of the respective memory cells to the respective threshold voltage of each desired state.

FIG. 4B illustrates the threshold voltage distributions after the odd page or pages being programmed. It can be seen that the disturb caused by the additional programming and floating gate-to-floating gate coupling of the memory cells has widened the distributions such that they overlap. In order to tighten up the distributions, a touch-up programming operation is performed **309**.

The touch-up programming operation comprises programming the data from the page buffer, that was previously read from the even page or pages, back to the memory cells. In one embodiment, the data is programmed back a certain voltage (e.g., 400 mV) higher. This has the effect of moving the lower ends of the distributions to higher threshold voltages and tightening the distributions.

The uncertain data from the uncertain locations **401-407** of FIG. 4A were not moved thus resulting in "tails" **410-416** on the distributions representing the uncertain data. However, these uncertain data are now "soft" errors (e.g., the least

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significant bits) instead of the “hard” errors (e.g., most significant bits) that resulted from the prior art touch-up programming operation.

The previous description, for purposes of illustration, started with programming the even page of data prior to programming the odd page of data. An alternate embodiment can comprise programming the odd page first, reading the odd page, programming the even page, then reprogramming the odd page.

FIG. 5 illustrates a functional block diagram of a memory device 500 as part of a memory system 520. The memory device 500 is coupled to a controller 510. The controller 510 may be a microprocessor or some other type of controlling circuitry. The memory device 500 has been simplified to focus on features of the memory that are helpful in understanding the present invention.

The memory device 500 includes an array 530 of non-volatile memory cells, such as the one illustrated previously in FIG. 2. The memory array 530 is arranged in banks of word line rows and bit line columns. In one embodiment, the columns of the memory array 530 are comprised of series strings of memory cells as illustrated in FIG. 2. As is well known in the art, the connections of the cells to the bit lines determines whether the array is a NAND architecture, an AND architecture, a NOR architecture, or another architecture.

Address buffer circuitry 540 is provided to latch address signals received through I/O circuitry 560. Address signals are received and decoded by a row decoder 544 and a column decoder 546 to access the memory array 530. It will be appreciated by those skilled in the art, with the benefit of the present description, that the number of address input connections depends on the density and architecture of the memory array 530. That is, the number of addresses increases with both increased memory cell counts and increased bank and block counts. The page buffer 573, as previously described, is coupled to the memory array for storing data to be programmed or that has been read.

The memory device 500 reads data in the memory array 530 by sensing voltage or current changes in the memory array columns using sense circuitry 550. The sense circuitry 550, in one embodiment, is coupled to read and latch a row of data from the memory array 530. The I/O circuitry 560 provides bidirectional data communication as well as address communication over a plurality of data connections 562 with the controller 510. Write circuitry 555 is provided to write data to the memory array.

Memory control circuitry 570 decodes signals provided on control connections 572 from the controller 510. These signals are used to control the operations on the memory array 530, including data read, data write (program), and erase operations. The memory control circuitry 570 may be a state machine, a sequencer, or some other type of control circuitry to generate the memory control signals. In one embodiment, the memory control circuitry 570 is configured to execute the method for programming with the modified touch-up programming operation.

The flash memory device illustrated in FIG. 5 has been simplified to facilitate a basic understanding of the features of the memory. A more detailed understanding of internal circuitry and functions of flash memories are known to those skilled in the art.

CONCLUSION

In summary, one or more embodiments include an improved multiple step programming method that reduces the chances of “hard” errors caused by an ECC engine assign-

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ing uncertain data to the wrong state. This can be accomplished by excluding the uncertain data from reprogramming during the touch-up operation.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement that is calculated to achieve the same purpose may be substituted for the specific embodiments shown. Many adaptations of the invention will be apparent to those of ordinary skill in the art. Accordingly, this application is intended to cover any adaptations or variations of the invention.

What is claimed is:

1. A method of operating a memory, comprising:
 - programming a memory cell;
 - reading the memory cell to determine a programmed threshold voltage of the memory cell;
 - if the programmed threshold voltage is within a threshold voltage distribution of a plurality of threshold voltage distributions, reprogramming the memory cell; and
 - if the programmed threshold voltage is not within a threshold voltage distribution of the plurality of threshold voltage distributions, leaving the memory cell at the programmed threshold voltage.
2. The method of claim 1, wherein programming a memory cell is performed as part of programming a group of memory cells.
3. The method of claim 1, wherein programming a memory cell comprises applying programming pulses to the memory cell until it reaches a desired threshold voltage.
4. The method of claim 3, wherein reprogramming the memory cell comprises applying programming pulses to the memory cell until it reaches a second desired threshold voltage.
5. The method of claim 4, wherein the second desired threshold voltage is higher than the desired threshold voltage.
6. The method of claim 1, wherein programming a memory cell comprises programming the memory cell to a particular data state corresponding to a first threshold voltage range, wherein reprogramming the memory cell comprises reprogramming the memory cell to the particular data state corresponding to a second threshold voltage range, and wherein the second threshold voltage range is different than the first threshold voltage range.
7. The method of claim 1, further comprising:
 - programming an adjacent memory cell after reading the memory cell and before reprogramming the memory cell.
8. The method of claim 1, wherein each threshold voltage distribution of the plurality of threshold voltage distributions corresponds to a data state to which the memory cell may be programmed.
9. A method of operating a memory, comprising:
 - applying programming pulses to a memory cell until it reaches a desired threshold voltage corresponding to a particular data state of a plurality of data states;
 - reading the memory cell to determine a programmed threshold voltage of the memory cell;
 - if the programmed threshold voltage is within a threshold voltage distribution corresponding to any data state of the plurality of data states, applying programming pulses to the memory cell until it reaches a second desired threshold voltage; and
 - if the programmed threshold voltage is not within a threshold voltage distribution corresponding to any data state of the plurality of data states, leaving the memory cell at the programmed threshold voltage.

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10. The method of claim 9, further comprising:
applying programming pulses to a second memory cell
adjacent the memory cell after reading the memory cell.
11. The method of claim 9, wherein the second desired
threshold voltage is higher than the desired threshold voltage. 5
12. A method of operating a memory, comprising:
programming a group of memory cells until each memory
cell of the group of memory cells reaches a respective
desired threshold voltage;
reading the group of memory cells to determine pro- 10
grammed threshold voltages of the memory cells of the
group of memory cells;
determining whether the programmed threshold voltages
of the memory cells of the group of memory cells are 15
within any threshold voltage distribution of a plurality of
threshold voltage distributions;
for those memory cells of the group of memory cells whose
programmed threshold voltages are within any threshold
voltage distribution of the plurality of threshold voltage 20
distributions, programming those memory cells until
each of those memory cells reaches a second respective
desired threshold voltage; and
for those memory cells of the group of memory cells whose
programmed threshold voltages are not within any 25
threshold voltage distribution of the plurality of thresh-
old voltage distributions, leaving each of those memory
cells at their respective programmed threshold voltage.
13. The method of claim 12, wherein programming a group
of memory cells comprises programming a page of memory 30
cells.

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14. The method of claim 13, further comprising:
programming a different page of memory cells after read-
ing the page of memory cells.
15. The method of claim 14, further comprising:
for those memory cells of the page of memory cells whose
programmed threshold voltages are within any threshold
voltage distribution of the plurality of threshold voltage
distributions, programming those memory cells until
each of those memory cells reaches its second respective
desired threshold voltage after programming the differ-
ent page of memory cells.
16. The method of claim 13, wherein programming a page
of memory cells comprises programming an even page of
memory cells.
17. The method of claim 16, further comprising:
programming an odd page of memory cells after reading
the even page of memory cells.
18. The method of claim 12, further comprising:
storing data read from the group of memory cells; and
using the stored data to program those memory cells whose
programmed threshold voltages are within any threshold
voltage distribution of the plurality of threshold voltage
distributions to their respective second desired threshold
voltages.
19. The method of claim 18, further comprising using the
stored data without error correction.
20. The method of claim 18, further comprising:
excluding, removing or inhibiting stored data correspond-
ing to those memory cells whose programmed threshold
voltages are not within any threshold voltage distribu-
tion of the plurality of threshold voltage distributions.

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